Notes on a More Generalized Yield Per Recruit Analysis For Crustaceans, Using Size-Specific Inputs

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February, 1979

Fisheries & Marine Service
Manuscript Report No. 1525

Fisheries and Marine Service

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•Cover design by Christine Rusk

Department of Fisheries and Oceans
Manuscript Report No. 1525

June, 1979

NOTES ON A MORE GENERALIZED YIELD PER RECRUIT ANALYSIS FOR CRUSTACEANS USING SIZE-SPECIFIC INPUTS

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Cat. No. Fs 97-4/1525 ISSN 0701-7618

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ABSTRACT

Caddy, J.F. 1979. Notes on a more generalized yield per recruit analysis for crustaceans using size-specific inputs. Fish. Mar. Serv. MS Rep. 1525.

The logic and computer programme listing in Fortran IV is presented together with input instructions and a sample run for yield per recruit analysis and population fecundity calculation for organisms such as crustaceans which show discontinuous growth. The analysis recognizes that size at age data are not readily obtainable directly, and employs size specific inputs for moult increment and frequency, proportion mature, size at first and full capture, and individual fecundity. The time scale of the model is basically determined by the intermoult interval, which values can be input as real values, or calculated from an exponential equation. Built into the model (specifically designed for Homarus americanus) is the assumption that berried (egg-bearing females) are not available to fishing mortality for the duration of egg bearing. (The berried lobster regulation requires discarding of egg-bearing females at sea.)

Key words: Lobster, crustaceans, yield per recruit, population dynamics, population fecundity.

RESUME

Caddy, J.F. 1979. Notes on a more generalized yield per recruit analysis for crustaceans using size-specific inputs. Fish. Mar. Serv. MS Rep. 1525.

Cette publication présente la logique et les énoncés d'un programme Fortran IV pour calculer la production par classe de recrutement et la fécondité d'une population d'organismes à croissance discontinue tels les crustacés. On présente aussi les instructions d'entrée et un exemple appliqué. L'analyse tient compte du fait que les données de taille à l'âge sont difficiles à obtenir directement; on y substitue des entrées spécifiques à la taille pour l'augmentation de taille par mue, la fréquence des mues, la proportion d'individus matures, la taille à la première capture et au seuil de vulnérabilité totale à l'engin de pêche, et la fécondité individuelle. L'intervalle entre les mues détermine l'échelle temporelle du modèle. On peut entrer cet intervalle comme valeur réelle ou le calculer au moyen d'un équation exponentielle. Le modèle est spécifiquement adapté à Homarus americanus; on y assume que les femelles

oeuvées sont exemptes de la mortalité attribuable à la pêche durant la période d'incubation. (Les réglements des pêches exigent le retour à la mer des femelles oeuvées.)

Introduction

A more flexible approach to yield/recruit analysis for crustaceans is presented, incorporating the concepts described by Caddy (1977), together with a listing and sample run for the programme in Fortran IV illustrating a way of using these concepts in yield/recruit analysis. The analysis is extended to estimate the relative population fecundity resulting from a given fishing regime.

Growth

Separating the two components of growth, increment and frequency, increment can be expressed conventionally by:

$L_{m+1} = \alpha_i L_m^{\beta i}$ for i = 1, 2 (males, females)

and frequency by either a) an exponential function relating intermoult period (Δt) to premoult size CL_m; i.e., $\Delta t_m = ce^{d(CL)m}$ which generate together growth curves of an assymptotic type; or b) observed values for moult frequency at size intervals over the range of sizes in the fishery, which can be specified before each run. Linear interpolation is then used to obtain an estimate of moult frequency at size intermediate between those sizes for which moult frequency is available.

Moult weight is obtained by the usual power function:

$$W_m = A(CL)_m^B$$

Gear Selection

A linear approximation to a selection ogive is used as a ramp function for proportion retained (p_m) to calculate size retention by the trap of small lobsters, which calls for estimates of first partial and full retention sizes respectively. After that, retention is considered complete with size until a knife-edge maximum size is reached, above which entry to the trap is impossible, and probability of capture drops to zero.

Relative Population Fecundity

Input values for proportion of mature at size (Pr_m) are read in for a series of sizes of females. From this, linear interpolation is used to estimate proportion mature at intermediate sizes. Population fecundity can then be estimated from the relationship between number of eggs produced and size:

$$Eggs_m = K(CL)_m^L$$

the number of eggs produced by survivors (N_m) to each successive moult group are calculated both before and after mortality at that size occurs (depending on whether fishing precedes or follows the period of eggs bearing in a particular fishery). Number of eggs produced at each successive moult size is calculated by:

$$E_m = N_m Pr_m Eggs_m$$

- values for E_m being accumulated for each moult group in essentially the same way as in Robinson MS (1978).

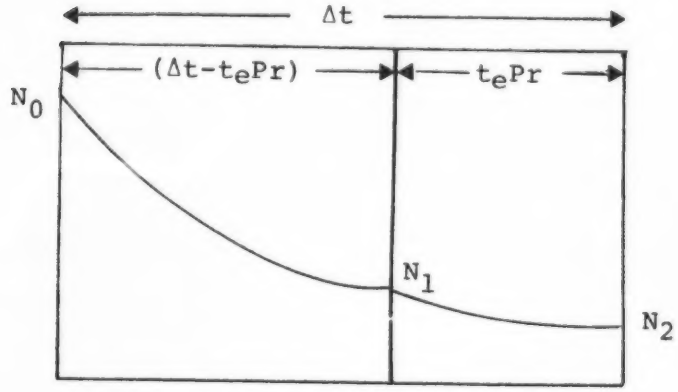
Mortality Formulation

Only one of the two hypotheses given in Caddy (1977) is still followed for natural mortality; namely, constant M per year. This formulation for yield and survivors for females is, however, modified to take into account for the females of the fraction of Δt when they are not available for retention (berried lobsters law); during this period (t_e) when eggs are held externally, they are assumed to be returned unharmed if caught.

For males, the formulations for yield from each moult group are as before; namely:

$$C_m = \frac{n_m f_m W_m}{F_m+M} \; 1-e^{-(F_m+M)\Delta t}$$

$$n_{m+1} = n_m e^{-(F_m+M)\Delta t}$$



Allowing for the fact that at any given size for which we have a value of Δt, mature and immature females may be present in the ratio Pr/1-Pr, the mean period during which this population is vulnerable to fishing, is given by:

	duration fishing	proportion of females
mature females	$\Delta t - t_e$	Pr
immature females	Δt	1-Pr

mean duration of period of fishing: $(\Delta t - t_e)Pr + \Delta t(1-Pr) = \Delta t - t_e Pr$.

Giving a formulation for survivors during the first part of Δt, we have:

$$N_1 = N_o e^{-(F+M)(\Delta t - t_e Pr)}$$

and assuming for the remainder of Δt (duration of $t_e pr$) only M applies,

$$N_2 = N_1 e^{-M t_e Pr}$$

Thus, the number of survivors at the end of the interval is:

$$N_2 = N_o e^{-F(\Delta t - t_e Pr) - M\Delta t}$$

Catch is given by:

$$C_m = \frac{n_m F_m W_m}{F_m + M} \; 1 - e^{-(F_m+M)\;(\Delta t - t_e Pr)}$$

For females, allowance must be made for the berried period, during Δt (the mean intermoult period for females, both mature and immature of a given size). In the programme there is a test to see that the period of external egg bearing t_e is not greater than or equal to the intermoult period read in for that size (an error message then occurs).

If Δt is the intermoult period, $\Delta t - t_e$ is the period available for fishing for mature females, and F is only applied over this time interval, although M applies throughout Δt. In calculating a correction for this factor, it was assumed that this period entirely preceded the period of egg bearing in the

intermoult period. This may not be entirely true for older females, particularly if multiple egg laying occurs in a given moult interval. In this case, a much more complex model requiring more information on the interaction of moulting and egg laying protocols would be needed.

Description of the Programmes

It is assumed that the moult interval preceding entry to the fishery contains 1,000 recruits, evenly spaced in size between PRECULL (the premoult carapace length giving the legal size CULL on moulting), and CULL. Outputs from the individual initial sizes (and the deterministically obtained series of postmoult sizes each of them generate) between PRECULL and CULL are added, and the yield, number of survivors (and relative fecundity for the females) expressed in terms of the size at first fishing and the fishing mortality rate applied. It is assumed that it is impossible to break down changes in size at first entry into smaller units than one moult increment, so that the size at first fishing is equivalent to delaying the fishery by full moult increments only. During the period between CULL and the first moult group fished, natural mortality reduces the number finally entering the fishery.

Results

The programme has been run for a set of input data, some of which (the size increment and length-weight relationship) are specific to inshore stocks in the Gulf of St. Lawrence, while the other parameter values have been assumed to be of the right order of magnitude for Maritime lobster stocks. In consequence, the results do not necessarily apply to any one stock, but appear to show the same general features observed as other analyses using a more conventional Beverton and Holt format.

More detailed comparisons will be needed to establish comparability: the main attempt here is to arrive at a method of calculation that uses, as far as possible, actual data easily obtainable from crustacean populations, where actual size at age data are not readily available.

A listing of the programme is given in Appendix II, and some typical outputs in Appendix III.

Acknowledgements

The author expresses his gratitude to Mrs. Joy Mendelson for her efforts in programming the model and to Douglas Robinson for useful discussion and input.

References

Caddy, J.F. 1977. Approaches to a simplified yield-per-recruit model for crustacea, with particular reference to the American lobster, Homarus Americanus. Fish. Mar. Serv. MS Rep. 1445, 14 p.

Robinson, D.G. 1978. Approaches to a simplified lobster stock recruitment model. CAFSAC Working Paper 78/35.

APPENDIX

Programme Lobster - Layout of Input File

Record length: 80 columns - card image

Card No.	Parameters	Format
1	IMR, ISEX, INTOPT, NMAX	4I3
2	XMINIT, PP, MR	3F10.6
3	CULL1, A(1), A(2), B(1), B(2), AA(1), AA(2), BB(1), BB(2)	F4.1, 8F9.7
4	TLEN1, TLEN2, TLEN3	3F6.1
5	NINT	I2
6	CL(I), I=1, NINT	13F6.1
7	XINTRD(I), I=1, NINT	20F4.1
8	NMAT	I2
9	CLM(I), I=1, NMAT	13F6.1
10	PROPM(I), I=1, NMAT	20F4.1

```
001002002012
 13.457      0.029933  0.1
63.50.0003307 0.001005 3.2068   2.9456  1.3785  1.3804  0.9555  0.9545
  50.0   80.0 125.0
 3
  60.0   90.0 200.0
 0.5 1.0 4.0
 3
  60.0   80.0   100.0
 0.0 0.8 1.0
```

Explanation of Parameters

1) IMR = 1 (no options).

   ISEX = 1 males.
   = 2 females (include cards 8, 9, 10).

   INTOPT = 1 use daily exponential formulation for XINT.
   = 2 calculate XINT from input table 1 (include cards 5, 6, 7).

   NMAX = max. no of moult groups contributing to the fishery.

2) XMINIT = constant of decreasing moult frequency with size (= 13.457).

   PP = parameter defining exponential decay in moult frequency with size (= 0.029933).

   MR = natural mortality rate.

3) CULL1 = legal cull size (= 63.5)(or initial size at recruitment to the fishery if size limit raised above CULL).

A(1) A(2) B(1) B(2) = length/weight parameters (males = 1, females = 2).

A(1) = 0.0003307

A(2) = 0.001005

B(1) = 3.2068

B(2) = 2.9456

AA(1) AA(2) BB(1) BB(2) are parameters of linear regression pre- to post-moult.

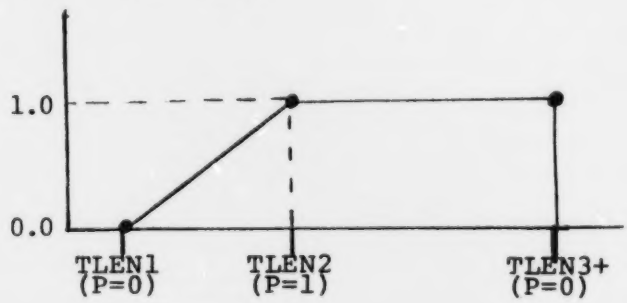
AA(1) = 1.3785

AA(2) = 1.3804

BB(1) = 0.9555

BB(2) = 0.9545

4) TLEN1 TLEN2 TLEN3 are the 3 x-coordinates of the graph (i.e. carapace length in mm) which predicts the probability of being retained by the trap. TLEN3 is the maximum size that can enter the trap.



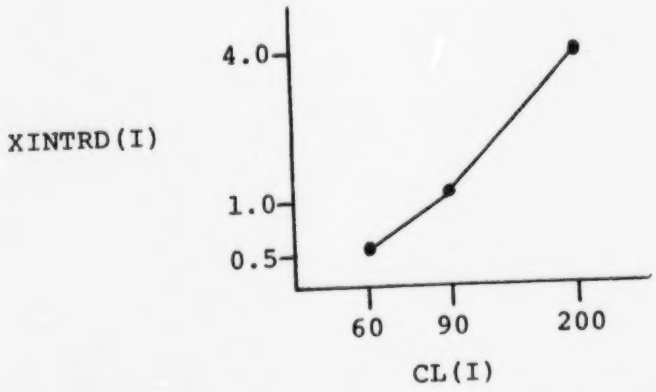
5) Include cards 5, 6, 7, only if intopt = 2; i.e. if intopt = 1, these cards are <u>not</u> read and should be omitted from deck.

NINT = # pts. on graph which predicts the time interval XINT as a function of carapace length.

6) CL(I), I = 1, NINT = vector with NINT pts., giving x-coordinates (i.e. carapace length in mm).

7) XINTRD(I), I = 1, NINT = vector with NINT pts. giving y-coordinates (i.e. values for XINT) corresponding to carapace lengths in 6).

Graph of NINT points



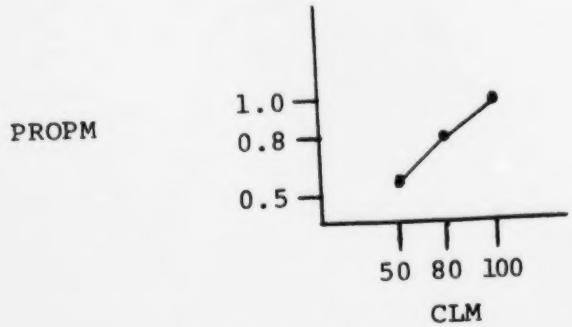
8) Include cards 8, 9, 10 only if ISEX = 2. If ISEX = 1 (males) omit cards 8, 9, 10.

NMAT = # of pts. on graph which predicts probability that a female is mature (egg-bearing) depending on carapace length.

9) CLM(I), I = 1, NMAT
vector of NMAT pts. for x-coordinates; i.e. carapace lengths at which the proportion of femals mature is known.

10) PROPM(I), I = 1, NMAT
vector of NMAT pts. for y-coordinates; i.e. values for proportion mature at that carapace length.

Graph of NMAT points



APPENDIX II

```
C
C    PROGRAMME LOBSTER - YIELD PER RECRUIT BY MOULT GROUP
C
      DIMENSION A(2),AA(2),B(2),BB(2)
      DIMENSION F(25),P(12,10),PRM(12,10),RNO(10),XINT(12,10)
      DIMENSION CL(20),XINTRD(20),CLM(20),PROPM(20),SLOPE(20)
      DIMENSION SAVE(6,25,9)
      REAL MLT(13,10),MLTWT(13,10),MR
C
C-----------------------------------------------------------------------
C
C    EACH RUN SPECIFIES THE EFFECT OF
C       A) DELAYING ENTRY BY UP TO 5 MOULT INCREMENTS
C            ABOVE LEGAL SIZE
C       B) A RANGE OF FISHING MORTALITIES F ON YIELD PER RECRUIT
C
C    BEFORE EACH RUN INITIALIZE IMR, ISEX AND INTOPT
C       IMR = 1 (NAT'L. MORTALITY RATE CONSTANT THROUGHOUT THE YEAR)
C       IMR = 2 (NAT'L MORTALITY RATE CONSTANT ON A MOULT INTERVAL BASIS)
C
C       ISEX = 1 (MALES)
C       ISEX = 2 (FEMALES - CALC. PRM FROM INPUT TBL -- USE CLM & PROPM)
C
C       INTOPT = 1 (USE DAILY INTERVAL FOR XINT)
C       INTOPT = 2 (CALCULATE XINT FROM INPUT TABLE -- CL & XINTRD)
C
C    CULL1 IS THE LEGAL CULL SIZE
C    A AND B ARE LENGTH/WEIGHT PARAMETERS (MALES=1, FEMALES=2)
C    AA AND BB ARE PARAMETERS OF LINEAR REGRESSION, PRE- TO POST- MOULT
C
C    MR     = NATURAL MORTALITY RATE
C    NMAX   = MAX. NO. OF MOULT GROUPS CONTRIBUTING TO THE FISHERY
C    NM1    = NMAX - 1
C    P(I)   = PROPORTION OF EACH MOULT GROUP RETAINED BY GEAR
C    PP     = PARAMETER DEFINING EXPONENTIAL DECAY IN MOULT
C               FREQUENCY WITH SIZE
C    XMINIT = CONSTANT OF DECREASING MOULT FREQUENCY WITH SIZE
C
C-----------------------------------------------------------------------
C
      READ(5,1001,END=990)IMR,ISEX,INTOPT,NMAX
 1001 FORMAT(4I3)
      READ(5,1002,END=990)XMINIT,PP,MR
 1002 FORMAT(3F10.6)
      READ(5,1003,END=990)CULL1,A(1),A(2),B(1),B(2),AA(1),AA(2),
     X  BB(1),BB(2)
 1003 FORMAT(F4.1,8F9.7)
      READ(5,1004,END=990)TLEN1,TLEN2,TLEN3
 1004 FORMAT(3F6.1)
      IF(INTOPT.EQ.1)GO TO 8
      READ(5,1005,END=990)NINT
 1005 FORMAT(I2)
      READ(5,1006,END=990)(CL(I),I=1,NINT)
 1006 FORMAT(13F6.1)
      READ(5,1007,END=990)(XINTRD(I),I=1,NINT)
 1007 FORMAT(20F4.1)
    8 IF(ISEX.EQ.1) GO TO 25
      READ(5,1008,END=990)NMAT
 1008 FORMAT(I2)
```

```
      READ(5,1009,END=990)(CLM(I),I=1,NMAT)
 1009 FORMAT(13F6.1)
      READ(5,1010,END=990)(PROPM(I),I=1,NMAT)
 1010 FORMAT(20F4.1)
C
C    PRINT INPUT CARD PARAMETERS
C
   25 WRITE(6,1025)
 1025 FORMAT(11X,'***** RUN PARAMETERS FOR THIS JOB ARE *****'//)
      GO TO (26,27),IMR
   26 WRITE(6,1026)IMR
 1026 FORMAT(' NATURAL MORTALITY RATE CONSTANT THROUGHOUT THE YEAR,',
     X ' IMR = ',I1)
      GO TO 28
   27 WRITE(6,1027)IMR
 1027 FORMAT(' NATURAL MORTALITY RATE CONSTANT ON A MOULT INTERVAL ',
     X ' BASIS, IMR = ',I1)
C
   28 GO TO (29,30),ISEX
   29 WRITE(6,1029)ISEX
 1029 FORMAT(' SEX IS MALE -- ISEX = ',I1)
      GO TO 35
   30 WRITE(6,1030)ISEX
 1030 FORMAT(' SEX IS FEMALE -- ISEX = ',I1)
C
   35 WRITE(6,1035)NMAX
 1035 FORMAT('0NMAX = ',I2)
      WRITE(6,1036)MR
 1036 FORMAT(' THE ANNUAL NATURAL MORTALITY RATE IS ',F4.1)
      IF(IMR.EQ.2)GO TO 39
      WRITE(6,1037)PP,XMINIT
 1037 FORMAT(' EXPONENTIAL DECAY IN MOULT FREQUENCY = ',F9.6,
     X       ' CONSTANT = ',F6.3/)
C
   39 WRITE(6,1039)
 1039 FORMAT(4X,'CULL1',5X,'AA1',5X,'BB1',5X,'AA2',5X,'BB2',
     X                  6X,'A1' ,6X,'B1' ,6X,'A2' ,6X,'B2')
      WRITE(6,1040)CULL1,AA(1),BB(1),AA(2),BB(2),A(1),B(1),A(2),B(2)
 1040 FORMAT(1X,9F8.4)
C
      WRITE(6,1045)TLEN1,TLEN2,TLEN3
 1045 FORMAT('0PROPORTIONS RETAINED BY EACH GEAR: '/
     X 10X,' AT TLEN1 = ',F6.1,', P(1) = 0.0'/
     X 10X,' AT TLEN2 = ',F6.1,', P(2) = 1.0'/
     X 10X,' AT TLEN3 = ',F6.1,', P(3) = 0.0')
C
      IF(INTOPT.EQ.1)GO TO 55
      WRITE(6,1051)NINT
 1051 FORMAT('0CALCULATE XINT USING GRAPH OF ',I3,' POINTS.')
      WRITE(6,1052)(CL(I),I=1,NINT)
 1052 FORMAT(' CARAPACE LENGTHS ARE ',20F6.1)
      WRITE(6,1053)(XINTRD(I),I=1,NINT)
 1053 FORMAT(' X INTERVALS USED ARE ',20F6.1)
C
   55 IF(ISEX.EQ.1)GO TO 100
      WRITE(6,1055)NMAT
 1055 FORMAT('0CALCULATE THE PROBABILITY OF BEING MATURE USING A ',
     X 'GRAPH OF ',I2,' POINTS')
      WRITE(6,1052)(CLM(I),I=1,NMAT)
```

```
      WRITE(6,1056)(PROPM(I),I=1,NMAT)
 1056 FORMAT(' PROBABILITY INTERCEPTS ON THE Y AXIS ARE ',20F6.1)
C
C-----------------------------------------------------------------------
C
C   GENERATE BOUNDS OF ARBITRARY MOULT GROUPS AND MEDIAN
C      LENGTHS AND WEIGHTS
C   PRE-MOULT SIZE OF 1ST MOULT GROUP ARBITRARILY SET TO THE
C      MINIMUM LEGAL SIZE
C
C-----------------------------------------------------------------------
C
  100 NM1=NMAX-1
C
C   CALCULATE PRE-CULL
C
      PRECUL=(CULL1/AA(ISEX)) ** (1./BB(ISEX))
      MLT(1,1)=PRECUL
C
C   CALCULATE MLT  (J,1), J=2,NMAX
C             MLTWT(J,1), J=1,NM1
C
      DO 110 J=1,NM1
      MLT(J+1,1)= AA(ISEX)*MLT(J,1)**BB(ISEX)
  110 MLTWT(J,1)=  A(ISEX)*MLT(J,1)** B(ISEX)/1000.
C
C   THEN CALCULATE MLT  (J,L),L=2,10 FOR J=1,NM1
C                  MLTWT(J,L) L=2,10 FOR J=1,NM1
C
      DO 120 J=1,NM1
      XINCR=(MLT(J+1,1)-MLT(J,1))/10.
      DO 120 L=2,10
      MLT  (J,L)=MLT(J,1) + (L-1)*XINCR
  120 MLTWT(J,L)=A(ISEX)*MLT(J,L) ** B(ISEX) / 1000.
C
C
      WRITE(6,1130)
 1130 FORMAT('0THE MLT MATRIX IS')
      DO 130 J=1,NM1
  130 WRITE(6,1135)(MLT(J,L),L=1,10)
 1135 FORMAT(1X,10F8.2)
      WRITE(6,1140)
 1140 FORMAT('0THE MLTWT MATRIX IS')
      DO 145 J=1,NM1
  145 WRITE(6,1135)(MLTWT(J,L),L=1,10)
C
C-----------------------------------------------------------------------
C
C   CALCULATE P(J) THE PROBABILITY OF A LOBSTER OF GIVEN MOULT LENGTH
C      WILL BE RETAINED BY THE FISHING GEAR
C      USING TLEN1 TLEN2 TLEN3
C
      BXX=TLEN2-TLEN1
      DO 240 J=1,NM1
      DO 240 L=1,10
      IF(MLT(J,L).LE.TLEN3)GO TO 210
      P(J,L)=0.0
      GO TO 240
  210 IF(MLT(J,L).LE.TLEN2)GO TO 220
```

```
      P(J,L)=1.0
      GO TO 240
  220 IF(MLT(J,L).LE.TLEN1)GO TO 230
      AXX=MLT(J,L)-TLEN1
      P(J,L)=AXX/BXX
      GO TO 240
  230 P(J,L)=0.0
  240 CONTINUE
C
      WRITE(6,1250)
 1250 FORMAT('0THE P MATRIX IS')
      DO 250 J=1,NM1
  250 WRITE(6,1135)(P(J,L),L=1,10)
C
C-----------------------------------------------------------------------
C
C   CALCULATE VALUES FOR XINT USING CONSTANT FORMULA
C      INTOPT = 1
C
C-----------------------------------------------------------------------
      IF(INTOPT.EQ.2)GO TO 300
C
      DO 280 J=1,NM1
      DO 280 L=1,10
  280 XINT(J,L)=XMINIT*EXP(PP*MLT(J,L)) / 365.
      GO TO 345
C
C-----------------------------------------------------------------------
C
C   CALCULATE VALUES FOR XINT BASED ON INPUT VALUES
C      X-AXIS IS CARAPACE LENGTH, Y-AXIS IS XINT
C      INTOPT = 2
C
  300 NINTM1=NINT - 1
C
      DO 310 N=1,NINTM1
      AXX=XINTRD(N+1)-XINTRD(N)
      BXX=    CL(N+1)-CL(N)
  310 SLOPE(N)=AXX/BXX
C
      DO 340 J=1,NM1
      DO 340 L=1,10
      IF(MLT(J,L).LE.CL(NINT))GO TO 320
      WRITE(6,1313)J,L,MLT(J,L),CL(NINT)
 1313 FORMAT('0ERROR MLT(',I2,',',I2,') = ',F10.2,
     X ' IS GREATER THAN GREATEST CARAPACE LENGTH = ',F6.1,
X    X ' ON XINT GRAPH')
      GO TO 340
C
  320 DO 330 N=1,NINTM1
      IF(MLT(J,L).GT.CL(N+1))GO TO 330
      XINT(J,L)=XINTRD(N)+SLOPE(N)*(MLT(J,L)-CL(N))
      GO TO 340
  330 CONTINUE
  340 CONTINUE
C
C
  345 WRITE(6,1345)
 1345 FORMAT('0THE XINT MATRIX IS')
```

```
      DO 349 J=1,NM1
  349 WRITE(6,1135)(XINT(J,L),L=1,10)
C
C-----------------------------------------------------------------------
C
C   CALCULATE THE PROBABILITY OF BEING A MATURE
C      EGG-BEARING FEMALE BASED ON THE CARAPACE LENGTH
C      AND PROBABILITY GIVEN IN A INPUT TABLE
C
      IF(ISEX.EQ.1)GO TO 400
      NMATM1=NMAT - 1
C
      DO 355 N=1,NMATM1
      AXX=PROPM(N+1)-PROPM(N)
      BXX=  CLM(N+1)-CLM(N)
  355 SLOPE(N)=AXX/BXX
C
      DO 370 J=1,NM1
      DO 370 L=1,10
      IF(MLT(J,L).LE.CLM(NMAT))GO TO 360
      PRM(J,L)=1.0
      GO TO 370
C
  360 DO 365 N=1,NMATM1
      IF(MLT(J,L).GT.CLM(N+1))GO TO 365
      PRM(J,L)=PROPM(N)+SLOPE(N)*(MLT(J,L)-CLM(N))
      IF(PRM(J,L).LT.0.0)PRM(J,L)=0.0
      GO TO 370
  365 CONTINUE
  370 CONTINUE
C
      WRITE(6,1372)
 1372 FORMAT('0THE PRM MATRIX IS')
      DO 380 J=1,NM1
  380 WRITE(6,1135)(PRM(J,L),L=1,10)
C
C-----------------------------------------------------------------------
C
C   INITIALIZE F(J) ARRAY
C      INCREASE F BY 0.1, IF F IS LESS THAN OR EQUAL TO 0.5, OTHERWISE
C      INCREASE F BY 0.2, UP TO 2.0 (13 ITERATIONS)
C
C   EGB = PERIOD IN YEARS THAT FEMALES ARE NOT AVAILABLE
C       FOR FISHING BECAUSE THEY ARE EGG-BEARING
C
  400 F(1)=0.00
      F(2)=0.025
      F(3)=0.05
      DO 410 I=4,9
  410 F(I)=(I-3) * 0.1
      DO 420 I=10,16
  420 F(I)=0.6 + (I-9)*0.2
C
      EGB=11/12
C
C-----------------------------------------------------------------------
C
C   THE OUTER LOOP TESTS EFFECTS OF DELAYING THE ONSET OF FISHING
C      BY 1 TO 5 MOULT INCREMENTS
```

```
C
C    THE SECOND LOOP SHOWS THE EFFECT OF INCREASING F
C
C-----------------------------------------------------------------------
C
      DO 700 IDELAY=1,6
      DO 675 I=1,16
C
C    INITIALIZE VARIABLES
C
      DO 510 L=1,10
  510 RNO(L)=100.
      TOTC  =0.0
      TOTEG1=0.0
      TOTEG2=0.0
      TOTINT=0.0
      TOTRN1=0.0
      TOTRN2=0.0
      TOTWT =0.0
C
C-----------------------------------------------------------------------
C
C THE CENTER LOOP DEFINES THE MOULT INTERVAL
C
C-----------------------------------------------------------------------
C
      DO 650 J=1,NM1
      DO 650 L=1,10
C
C    REDEFINE FISHING RATE BY MOULT GROUP
C
      IF(ISEX.EQ.2)GO TO 615
      XINTER=XINT(J,L)
      GO TO 630
C
C    FOR FEMALES ONLY -- CHECK VALIDITY OF XINT
C
  615 EP=EGB*PRM(J,L)
      IF(XINT(J,L).LE.EP)GO TO 619
      XINTER=XINT(J,L)-EP
      GO TO 630
C
  619 IF(I.GT.1)GO TO 625
      WRITE(6,1619)J,L,MLT(J,L)
 1619 FORMAT('0WARNING * PREDICTED MOULT INTERVAL FOR FEMALES AT SIZE',
     X ' MLT(', I2, ',', I2, ') = ', F8.2/
     X 11X,' IS TOO SHORT FOR THE PERIOD OF EGG-BEARING',
     X ' PREDICTED AT THIS SIZE * ')
      WRITE(6,1620)XINT(J,L),EP
 1620 FORMAT(' XINT(J,L) = ',F8.2,' EP = ',F8.2)
      WRITE(6,1621)
 1621 FORMAT(' XINTER SET EQUAL TO XINT(J,L) ')
C
  625 XINTER=XINT(J,L)
C
  630 FR=F(I)*P(J,L)
      IF(J.LT.IDELAY)FR=0.0
C
C    CALCULATE YIELD IN NUMBERS, WEIGHT AND ACCUMULATED CATCH FOR COHORT
```

```
C
      EXPLOI=FR/(FR+MR)
      EFPM  =EXP(-(FR+MR)*XINTER)
      C=RNO(L)*EXPLOI*(1.-EFPM)
      WT=C*MLTWT(J,L)
      TOTC =TOTC+C
      TOTWT=TOTWT+WT
C
C   CALCULATE NUMBER OF SURVIVORS
C
      RNO1=RNO(L)
      IF(ISEX.EQ.2)GO TO 635
      RNO(L)=RNO(L)*EXP(-(MR+FR)*XINTER)
      GO TO 640
  635 RNO(L)=RNO(L)*EXP(-FR*XINTER-MR*XINT(J,L))
  640 RNO2=RNO(L)
C
      IF(J.LT.NM1)GO TO 641
      TOTRN1=TOTRN1+RNO1
      TOTRN2=TOTRN2+RNO2
C
C   CALCULATE NUMBER OF EGGS PRODUCED BY INITIAL/FINAL SPAWNER BIOMASS
C
  641 IF(ISEX.EQ.1) GO TO 650
      EGGS=(MLT(J,L)*0.025)**2.8647
      EGGS=EGGS/1000.
      VALUE =RNO1*PRM(J,L)*EGGS
      TOTEG1=TOTEG1+VALUE
      VALUE =RNO2*PRM(J,L)*EGGS
      TOTEG2=TOTEG2+VALUE
C
  650 CONTINUE
C
      IF(TOTC.LT.0.00001) GO TO 655
      AVWT=TOTWT/TOTC
      GO TO 660
  655 AVWT=0.0
C
  660 SAVE(IDELAY,I,1)=TOTC
      SAVE(IDELAY,I,2)=AVWT
      SAVE(IDELAY,I,3)=TOTWT
      SAVE(IDELAY,I,4)=TOTRN1
      SAVE(IDELAY,I,5)=TOTRN2
      SAVE(IDELAY,I,6)=TOTEG1
      SAVE(IDELAY,I,7)=TOTEG2
C
  675 CONTINUE
  700 CONTINUE
C
      DO 800 IDELAY=1,6
      DO 800 I=1,16
      IF(SAVE(IDELAY,1,6).GT.0.0)GO TO 750
      SAVE(IDELAY,I,8)=99999.9
      GO TO 751
  750 SAVE(IDELAY,I,8)=SAVE(IDELAY,I,6)/SAVE(IDELAY,1,6)*100.
  751 IF(SAVE(IDELAY,1,7).GT.0.0)GO TO 799
      SAVE(IDELAY,I,9)=99999.9
      GO TO 800
  799 SAVE(IDELAY,I,9)=SAVE(IDELAY,I,7)/SAVE(IDELAY,1,7)*100.
```

```
  800 CONTINUE
C
C-----------------------------------------------------------------------
C
C  PRINT RESULTS IN TABLE FORMAT
C
      WRITE(6,1820)
 1820 FORMAT('1TOTAL CATCH TABULATED ACCORING TO MOULT',
     X ' GROUP SIZE AT FIRST CAPTURE AND FISHING MORTALITY')
      DO 825 IROW=1,6
      II=7-IROW
  825 WRITE(6,1850)II,(SAVE(II,I,1),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
      WRITE(6,1840)
 1840 FORMAT('1MEAN CATCH WEIGHT TABULATED ACCORDING TO MOULT',
     X ' GROUP SIZE AND FISHING MORTALITY AT FIRST CAPTURE'//)
      DO 850 IROW=1,6
      II=7-IROW
  850 WRITE(6,1850)II,(SAVE(II,I,2),I=1,16)
 1850 FORMAT('0DELAY = ',I1,16F7.2)
      WRITE(6,1860)(F(I),I=1,16)
 1860 FORMAT('0',9X,16(3X,F4.2),'  F')
C
      WRITE(6,1875)
 1875 FORMAT('1YIELD IN WEIGHT TABULATED ACCORDING TO MOULT',
     X ' GROUP SIZE AND FISHING MORTALITY AT FIRST CAPTURE'//)
      DO 900 IROW=1,6
      II=7-IROW
  900 WRITE(6,1850)II,(SAVE(II,I,3),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
      WRITE(6,1910)
 1910 FORMAT('1RNO BEFORE FISHING - RNO1'//)
      DO 915 IROW=1,6
      II=7-IROW
  915 WRITE(6,1850)II,(SAVE(II,I,4),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
      WRITE(6,1920)
 1920 FORMAT('1RNO AFTER FISHING - RNO2'//)
      DO 925 IROW=1,6
      II=7-IROW
  925 WRITE(6,1850)II,(SAVE(II,I,5),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
      IF(ISEX.EQ.1)GO TO 990
      WRITE(6,1950)
 1950 FORMAT('1NUMBER OF EGGS TABULATED ACCORDING TO MOULT',
     X ' GROUP SIZE AND FISHING MORTALITY AT FIRST CAPTURE'//)
      WRITE(6,1951)
 1951 FORMAT(' ',10X,'USING RNO1'//)
      DO 950 IROW=1,6
      II=7-IROW
  950 WRITE(6,1850)II,(SAVE(II,I,8),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
      WRITE(6,1950)
      WRITE(6,1952)
```

```
 1952 FORMAT(' ',10X,'USING RNO2'//)
      DO 960 IROW=1,6
      II=7-IROW
  960 WRITE(6,1850)II,(SAVE(II,I,9),I=1,16)
      WRITE(6,1860)(F(I),I=1,16)
C
  990 STOP
      END
```

APPENDIX III

Total catch tabulated according to moult group size at first capture and fishing mortality.

Delay = 6	0.0	142.23	249.59	331.19	393.67	441.89	479.41	532.18	565.84	588.10	603.35	614.14	622.01	627.90
Delay = 5	0.0	207.62	349.89	448.44	517.53	566.61	601.98	647.13	672.93	688.76	699.16	706.44	711.81	715.96
Delay = 4	0.0	260.80	426.79	534.19	605.00	652.71	685.63	725.92	748.38	762.32	771.78	778.68	783.98	788.20
Delay = 3	0.0	301.68	484.09	596.87	668.45	715.28	746.98	785.41	807.14	821.06	830.85	838.21	843.98	848.66
Delay = 2	0.0	324.34	515.59	631.38	703.74	750.65	782.33	821.04	843.48	858.30	869.03	877.27	883.87	889.30
Delay = 1	0.0	333.86	528.94	646.24	719.26	766.55	798.57	838.06	861.38	877.10	888.68	897.73	905.06	911.18
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Mean catch weight tabulated according to moult group size and fishing mortality at first capture

Delay = 6	0.0	1.16	1.15	1.14	1.13	1.12	1.11	1.09	1.08	1.07	1.06	1.06	1.05	1.05
Delay = 5	0.0	1.00	0.97	0.95	0.93	0.90	0.89	0.85	0.83	0.81	0.79	0.78	0.77	0.77
Delay = 4	0.0	0.87	0.83	0.79	0.76	0.73	0.70	0.66	0.63	0.61	0.59	0.58	0.56	0.56
Delay = 3	0.0	0.77	0.72	0.68	0.63	0.60	0.57	0.52	0.49	0.46	0.44	0.43	0.42	0.41
Delay = 2	0.0	0.72	0.66	0.61	0.57	0.53	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.32
Delay = 1	0.0	0.70	0.64	0.58	0.53	0.49	0.46	0.41	0.37	0.34	0.32	0.30	0.29	0.28
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Yield in weight tabulated according to moult group size and fishing mortality at first capture.

Delay = 6	0.0	46.32	287.53	377.63	444.53	494.48	531.99	581.97	611.44	629.49	641.04	648.79	654.24	658.26
Delay = 5	0.0	60.90	340.75	425.43	478.97	512.43	532.95	552.12	557.24	557.00	555.03	552.78	550.77	549.18
Delay = 4	0.0	69.30	354.05	423.37	459.29	476.14	482.29	479.88	471.07	461.92	454.07	447.75	442.77	438.90
Delay = 3	0.0	73.64	349.36	403.25	424.36	428.73	424.96	409.04	392.32	378.32	367.24	358.56	351.73	346.29
Delay = 2	0.0	75.12	341.15	385.39	397.95	395.45	386.39	363.34	342.26	325.28	311.92	301.33	292.80	285.80
Delay = 1	0.0	75.46	336.17	376.02	384.78	379.23	367.78	341.35	318.01	299.32	284.53	272.67	262.98	254.91
F	0.0	0.1	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Number of spawners before fishing.

Delay = 6	213.92	160.90	121.75	92.71	71.06	54.84	42.62	26.27	16.63	10.79	7.15	4.83	3.31	2.29
Delay = 5	213.92	142.39	95.26	64.07	43.32	29.46	20.14	9.58	4.66	2.31	1.17	0.60	0.31	0.17
Delay = 4	213.92	129.43	78.66	48.03	29.47	18.17	11.26	4.39	1.74	0.71	0.29	0.12	0.05	0.02
Delay = 3	213.92	120.69	68.34	38.85	22.17	12.70	7.30	2.44	0.83	0.29	0.10	0.04	0.01	0.00
Delay = 2	213.92	116.35	63.49	34.76	19.09	10.52	5.82	1.80	0.56	0.18	0.06	0.02	0.01	0.00
Delay = 1	213.92	114.69	61.68	33.27	18.00	9.77	5.32	1.59	0.48	0.15	0.05	0.01	0.00	0.00
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Number of eggs tabulated according to moult group size and fishing mortality at first capture (expressed as a percent of egg production of unfished stocks).

Delay = 6	100.00	84.18	72.75	63.20	56.28	50.95	46.82	41.05	37.43	35.09	33.54	32.49	31.77	31.27
Delay = 5	100.00	76.67	60.69	49.61	41.85	36.35	32.39	27.38	24.57	22.90	21.85	21.16	20.69	20.36
Delay = 4	100.00	70.64	51.96	39.88	31.92	26.58	22.91	18.47	16.06	14.62	13.68	13.03	12.56	12.20
Delay = 3	100.00	66.13	45.70	33.13	25.20	20.06	16.62	12.56	10.35	9.01	8.11	7.47	6.99	6.62
Delay = 2	100.00	63.74	42.48	29.73	21.85	16.84	13.52	9.63	7.52	6.21	5.32	4.68	4.19	3.80
Delay = 1	100.00	62.79	41.23	28.42	20.58	15.63	12.37	8.55	6.48	5.20	4.33	3.70	3.21	2.83
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Number of spawners after fishing.

Delay = 6	151.37	113.78	86.03	65.46	50.14	38.66	30.01	18.47	11.67	7.56	5.01	3.38	2.31	1.60
Delay = 5	151.37	100.70	67.33	45.25	30.58	20.78	14.20	6.74	3.27	1.62	0.82	0.42	0.22	0.12
Delay = 4	151.37	91.54	55.60	33.93	20.81	12.82	7.94	3.09	1.23	0.50	0.20	0.09	0.04	0.02
Delay = 3	151.37	85.37	48.33	27.46	15.66	8.97	5.15	1.72	0.58	0.20	0.07	0.02	0.01	0.00
Delay = 2	151.37	82.31	44.90	24.58	13.49	7.43	4.11	1.27	0.40	0.12	0.04	0.01	0.00	0.00
Delay = 1	151.37	81.14	43.63	23.53	12.73	6.90	3.76	1.12	0.34	0.10	0.03	0.01	0.00	0.00
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00

Number of eggs tabulated accordingly to moult group size and fishing mortality at first capture (expressed as a percentage of egg production of unfished stock).

Delay = 6	100.00	82.05	68.56	58.36	50.59	44.64	40.04	33.66	29.69	27.15	25.48	24.36	23.59	23.06
Delay = 5	100.00	73.98	56.26	44.09	35.64	29.70	25.48	20.22	17.35	15.68	14.66	14.01	13.56	13.26
Delay = 4	100.00	67.71	47.39	34.42	26.02	20.47	16.73	12.34	10.06	8.75	7.93	7.38	6.99	6.69
Delay = 3	100.00	63.16	41.29	28.06	19.90	14.75	11.40	7.60	5.68	4.56	3.85	3.36	3.00	2.73
Delay = 2	100.00	60.84	38.29	25.06	17.12	12.22	9.10	5.64	3.91	2.93	2.30	1.87	1.55	1.32
Delay = 1	100.00	59.93	37.16	23.95	16.12	11.33	8.31	5.00	3.37	2.44	1.86	1.47	1.18	0.97
F	0.0	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00